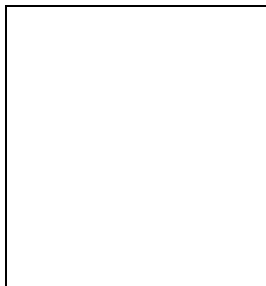


Jet quenching

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High- p_t particles produced in nucleus-nucleus collisions constitute a powerful tool to study the medium properties. The energy loss resulting from the propagation of these particles in the produced medium translates into a suppression of the high- p_t yields. These effects are usually associated to medium-induced gluon radiation which, in turn, predicts a broadening of the jet-like signals. Both the energy loss and the jet broadening are expected to increase proportionally to the medium density. In the more realistic case of a dynamically expanding medium, the gluon radiation becomes anisotropic due to the presence of a preferred direction in the transverse plane with respect to the axis of propagation. This anisotropy translates into deformed jet-shapes which provide new possibilities to study these flows by high- p_t measurements.

1 Introduction

Recent results at high transverse momentum from RHIC¹ on the inclusive particle suppression and the absence of away-side two particle correlations in central heavy ion collisions, together with the negative-effect results from the reference deuteron-gold run, suggest the formation of a very dense partonic medium with which the triggered particles interact strongly. The nature of this medium is still unknown and the study of its properties is the main goal of the experimental program of high-energy heavy ion collisions. More differential measurements of particles with high transverse momentum will give very valuable information as explained in the next sections.

In heavy ion collisions, the particles produced perturbatively at high transverse momentum are expected to be uncorrelated from the small transverse momentum *bulk*. At the same time, this high-multiplicity state is expected to form a deconfined and thermalized medium which modifies the properties of the parton shower developed by the high- p_t particles. The formalism to compute the medium-induced gluon radiation has been developed using several techniques and different approximations². Apart from details, most of the main results depend on coherence effects which suppress gluon radiation at small transverse momentum and/or large energies

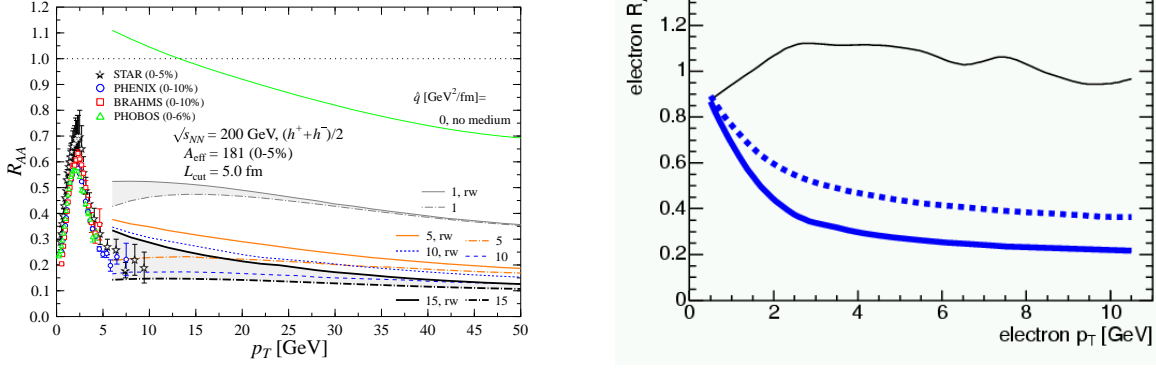


Figure 1: Left: nuclear modification factor R_{AA} for charged particles in central AuAu collisions at $\sqrt{s} = 200$ GeV compared with theoretical curves ⁶ for different values of \hat{q} . Right: Prediction ⁸ for the suppression of electrons coming from the decay of charm quarks in central AuAu collisions at $\sqrt{s} = 200$ GeV.

$k_t^2 \lesssim \hat{q}L$, $\omega \gtrsim \hat{q}L^2$, where the transport coefficient \hat{q} depends on properties of the medium as the density. This results in the well-known quadratic dependence of the radiative energy loss with the traverse length of the medium. Moreover, the medium-modification of the transverse momentum spectrum of radiated gluons translates into a jet broadening $\langle k_t \rangle \sim \Delta E L / \alpha_s$ ³. One of the main predictions of this formalism is, then, the broadening of the associated gluon radiation when compared with the evolution in the vacuum.

2 Energy loss and jet quenching

The medium-induced gluon radiation spectrum $\omega dI/d\omega$ depends on the length of the medium and the transport coefficient \hat{q} . In the absence of a more elaborated formalism, taking into account interference effects on multiple gluon radiation, the independent gluon emission approximation is usually taken. In this way, the probability that an additional energy ΔE is radiated by medium effect is given by the *quenching weights* ^{4,5} $P(\Delta E)$ and the medium-modified fragmentation functions are modeled by the convolution $D_{i \rightarrow h}^{\text{med}} = P(\Delta E) \otimes D_{i \rightarrow h}$. These medium-modified fragmentation functions can be used to compute the cross section for the production of a hadron h through the perturbative expression [for precise definitions of the convolutions see e.g. ⁶]

$$\frac{d\sigma^{AA \rightarrow h}}{dp_t} \sim f_i^A(x_1, Q^2) \otimes f_j^A(x_2, Q^2) \otimes \sigma^{ij \rightarrow k} \otimes D_{i \rightarrow h}^{\text{med}}(z, \mu_F) \quad (1)$$

The strategy is then to fit the best value of \hat{q} that reproduces the experimental suppression measured by the ratio

$$R_{AA}(p_t) = \frac{dN^{AA}/dp_t}{N_{\text{coll}} dN^{pp}/dp_t}. \quad (2)$$

The transport coefficient \hat{q} is proportional to the medium density. Thus, comparing the different \hat{q} obtained by applying this procedure to different systems, information about the density of the media is obtained. One limitation, however, appears when the medium is very dense and the suppression is so strong that the effect is dominated by surface emission ^{6,7}. In this case, the measure gives only a lower limit for the transport coefficient ⁶. In order to improve the determination of the medium properties, one possible solution is to study the case of heavy quarks ⁸. In this case, the radiation is suppressed by mass terms ⁹ and, hence, the effect is smaller. In Fig.1 the prediction ⁸ for the suppression of electrons from the decay of charm quarks at RHIC is presented using the transport coefficient obtained from the light meson case.

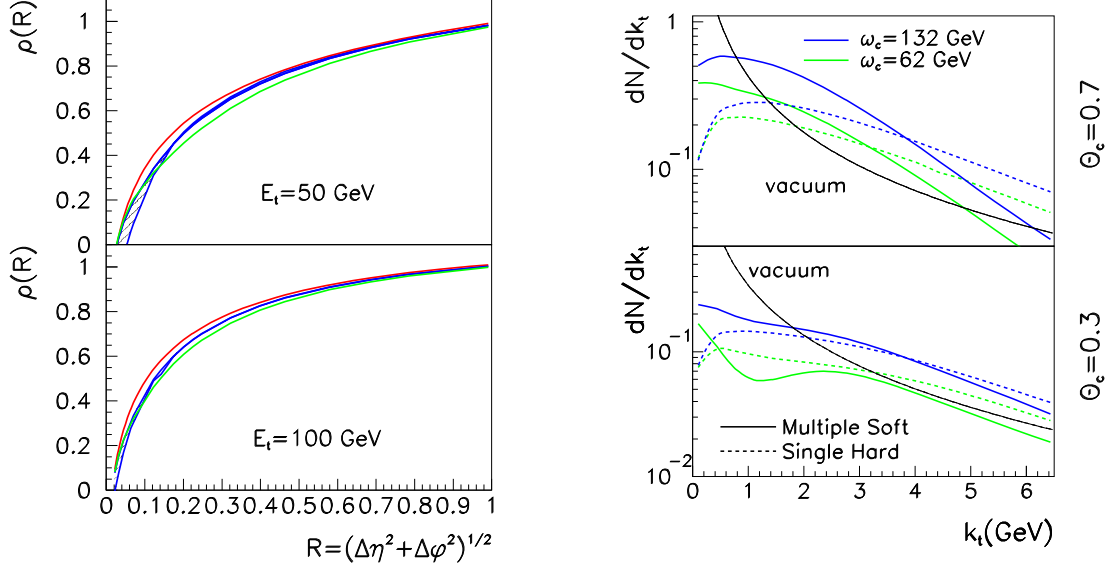


Figure 2: Left: Fraction of the jet energy inside a cone $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ for a 50 GeV and 100 GeV quark jet fragmenting in the vacuum (red curves) and a hot medium. Right: Comparison of the vacuum and medium-induced part of the gluon multiplicity distributions inside a cone jet of size $R = \Theta_c$. Figures taken from ¹⁰.

3 Medium-modified jet shapes

The structure of the jets is expected to be strongly modified when developed in a medium. The larger emission angle of the medium-induced spectrum translates into a broadening of the jet shapes. Although the broadening in energy could remain small for moderate transport coefficients, the intrajet multiplicity distribution is expected to present a harder spectrum in the transverse momentum with respect to the jet axis¹⁰ (see Fig. 2). This situation would be ideal for the study of medium-modified jet shapes at the LHC as i) it would allow for a good calibration of the jet energy (essential in order to study the jet properties) for the moderate values of the jet cone ($R \sim 0.3$) to be measured in the high-multiplicity environment of a heavy ion collision; and ii) the broadening produced in the intrajet multiplicities would be sizable enough to measure with high precision the medium effects.

A more interesting situation is, however, when the high- p_t particle travels through a flowing medium. In this case, the flow introduces a preferred direction in the medium-induced gluon radiation, producing asymmetric jet shapes¹¹ (see Fig. 3). These asymmetries are, in this way, a measurement of the flow field in a medium. Interestingly, preliminary results¹² from RHIC on high- p_t two particle correlations show a strong elongation of the jet-like signal in the longitudinal direction for central gold-gold collisions. In the spirit of the effects shown in Fig. 3, this elongation is produced by the strong longitudinal flow present in these collisions.

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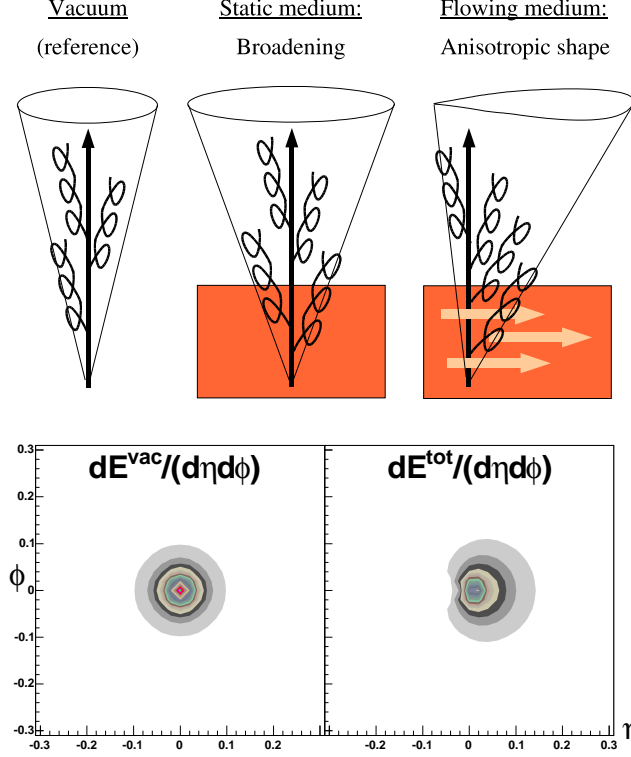


Figure 3: Upper part: sketch of the distortion of the jet energy distribution in the presence of a medium with or without collective flow. Lower part: calculated distortion of the jet energy distribution in the $\eta \times \phi$ -plane for a 100 GeV jet. The right hand-side is for an average medium-induced energy of 23 GeV and equal contributions from density and flow effects. Figures taken from ¹¹.

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